US006535811B1

(12) **United States Patent**
Rowland et al.

(10) **Patent No.:** **US 6,535,811 B1**
(45) **Date of Patent:** **Mar. 18, 2003**

(54) **SYSTEM AND METHOD FOR REAL-TIME ELECTRONIC ENGINE CONTROL**

(75) Inventors: **Zach L. Rowland**, Bowling Green, KY (US); **Jimmy D. Claiborne**, Scottsville, KY (US); **David Edward Heath**, Bowling Green, KY (US); **John D. Meaney**, Hartland, MI (US)

(73) Assignee: **Holley Performance Products, Inc.**, Bowling Green, KY (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 91 days.

(21) Appl. No.: **09/699,407**

(22) Filed: **Oct. 31, 2000**

Related U.S. Application Data

(60) Provisional application No. 60/163,253, filed on Nov. 3, 1999.

(51) **Int. Cl.**[7] **F02D 45/00**
(52) **U.S. Cl.** **701/115**
(58) **Field of Search** 701/115

(56) **References Cited**

U.S. PATENT DOCUMENTS

4,182,278 A	1/1980	Coakwell	123/1 A
4,331,121 A	5/1982	Stokes	123/575
4,467,764 A	8/1984	Takasu et al.	123/416
4,480,595 A	11/1984	Hobby et al.	123/1 A
4,494,488 A	1/1985	Wheatley	123/1 A
4,503,823 A	3/1985	Shibukawa et al.	123/406.66
4,572,140 A	2/1986	Wheatley	123/541
4,683,843 A	8/1987	Norcia et al.	123/1 A
4,750,453 A	6/1988	Valdespino	123/1 A
4,798,190 A	1/1989	Vaznaian et al.	123/531
4,827,888 A	5/1989	Vaznaian et al.	123/531
4,840,157 A	6/1989	Furrow	123/352
4,960,080 A	10/1990	O'Neill et al.	123/254
5,088,464 A	2/1992	Meaney	123/478
5,091,858 A	2/1992	Paielli	701/115
5,174,263 A	12/1992	Meaney	123/478
5,287,281 A	2/1994	Meaney	701/105
5,341,785 A	8/1994	Meaney	123/452
5,444,628 A	8/1995	Meaney et al.	701/109
5,699,776 A	12/1997	Wood et al.	123/531
6,009,372 A *	12/1999	Baker et al.	701/115

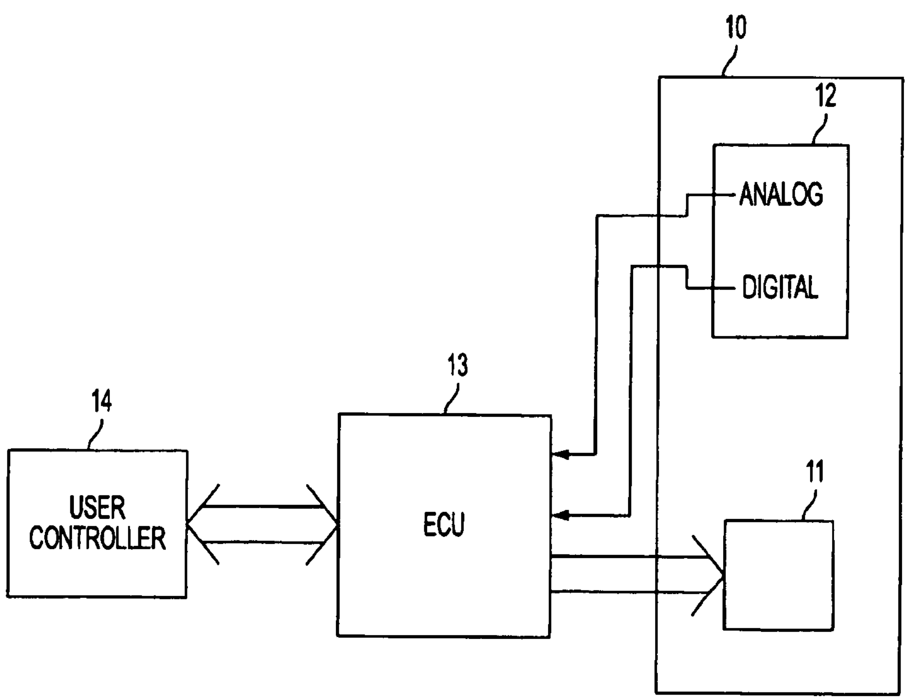
* cited by examiner

Primary Examiner—Andrew M. Dolinar
(74) *Attorney, Agent, or Firm*—Hunton & Williams

(57) **ABSTRACT**

A method and system for controlling an engine is disclosed. The method and system accomplish engine control based on one or more defined relationships. The present invention permits a user to adjust the defined relationships that are used to control the engine. Those adjustments are rewritten to the controller in real-time without interrupting the control operation.

11 Claims, 13 Drawing Sheets



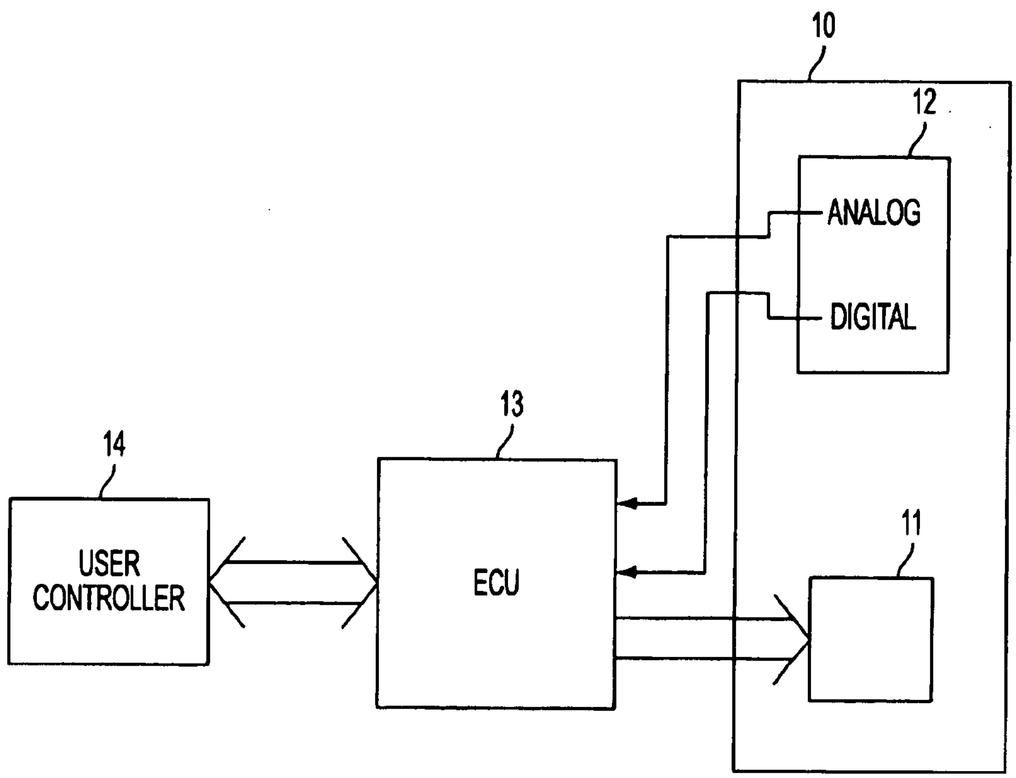


FIG. 1

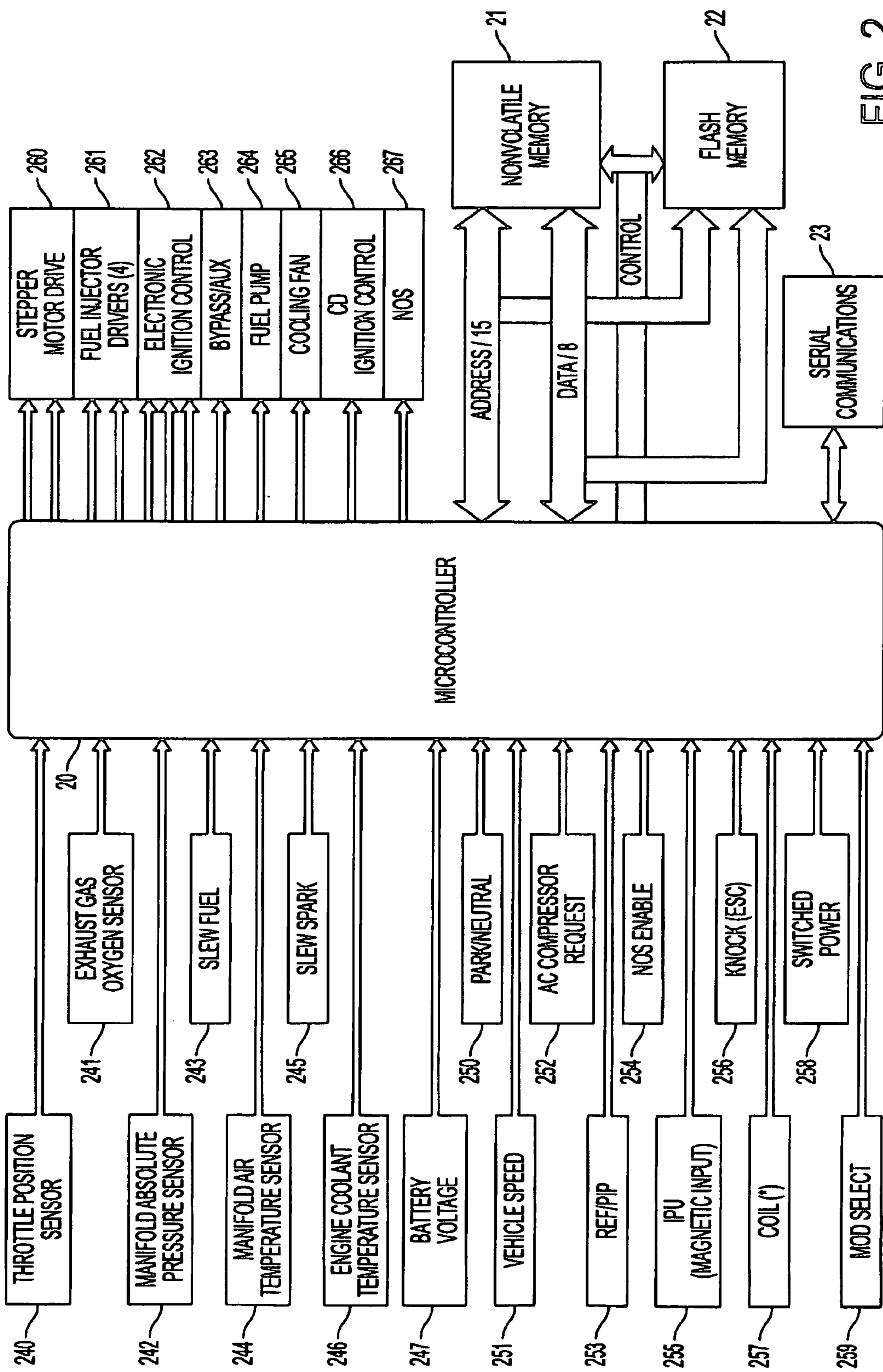

STEPPER MOTOR DRIVE
FUEL INJECTOR DRIVERS (4)
ELECTRONIC IGNITION CONTROL
BYPASS/AUX
FUEL PUMP
COOLING FAN
CD IGNITION CONTROL
NOS
260
261
262
263
264
265
266
267
NONVOLATILE MEMORY
21
FLASH MEMORY
22
CONTROL
ADDRESS / 15
DATA / 8
SERIAL COMMUNICATIONS
23
MICROCONTROLLER
20
THROTTLE POSITION SENSOR
240
EXHAUST GAS OXYGEN SENSOR
241
MANIFOLD ABSOLUTE PRESSURE SENSOR
242
SLEW FUEL
243
MANIFOLD AIR TEMPERATURE SENSOR
244
SLEW SPARK
245
ENGINE COOLANT TEMPERATURE SENSOR
246
BATTERY VOLTAGE
247
PARK/NEUTRAL
250
VEHICLE SPEED
251
AC COMPRESSOR REQUEST
252
REF/PIP
253
NOS ENABLE
254
IPU (MAGNETIC INPUT)
255
KNOCK (ESC)
256
COIL (-)
257
SWITCHED POWER
258
MOD SELECT
259

FIG. 2

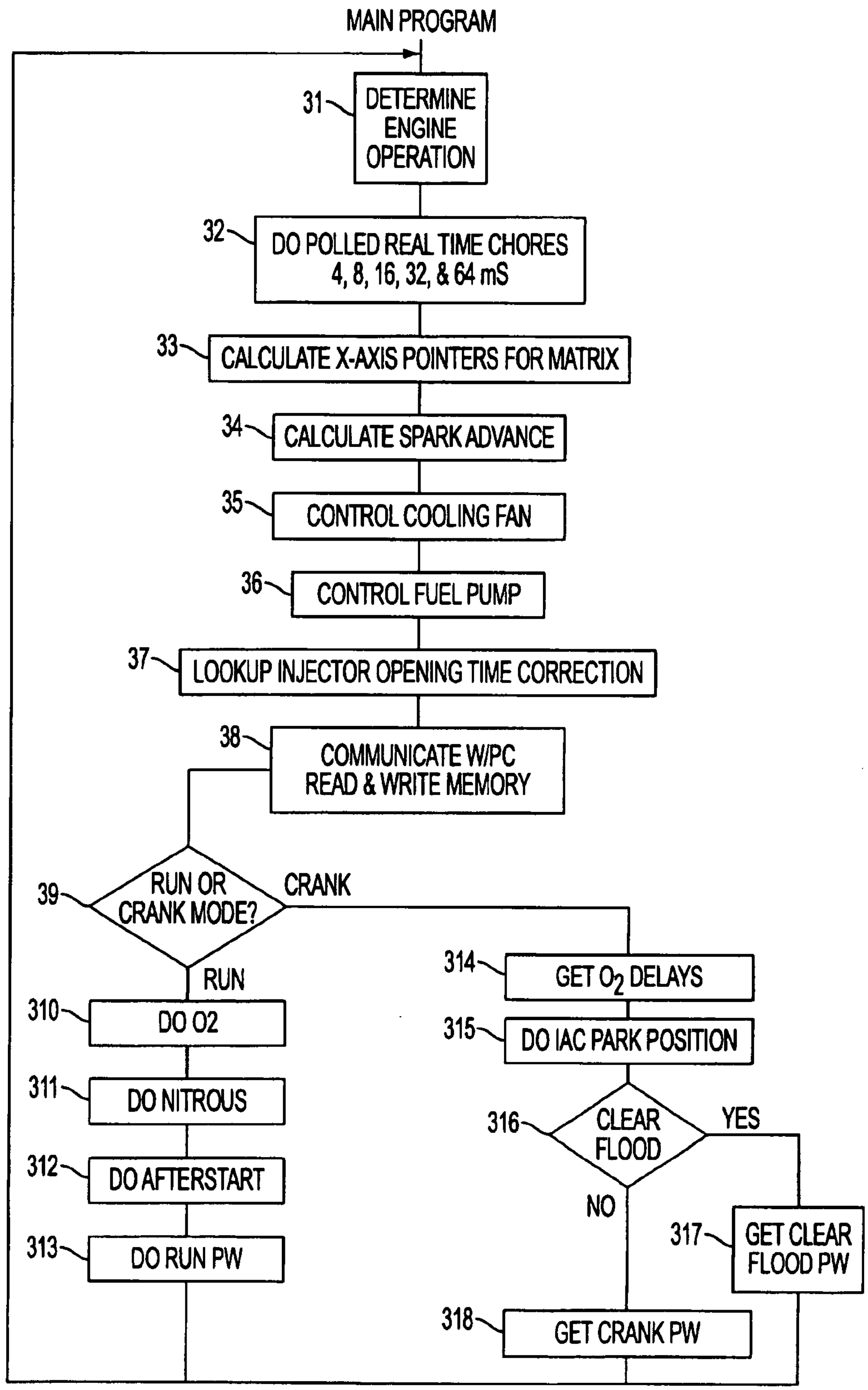

MAIN PROGRAM
31 DETERMINE ENGINE OPERATION
32 DO POLLED REAL TIME CHORES 4, 8, 16, 32, & 64 mS
33 CALCULATE X-AXIS POINTERS FOR MATRIX
34 CALCULATE SPARK ADVANCE
35 CONTROL COOLING FAN
36 CONTROL FUEL PUMP
37 LOOKUP INJECTOR OPENING TIME CORRECTION
38 COMMUNICATE W/PC READ & WRITE MEMORY
39 RUN OR CRANK MODE?
CRANK
RUN
310 DO O2
311 DO NITROUS
312 DO AFTERSTART
313 DO RUN PW
314 GET O2 DELAYS
315 DO IAC PARK POSITION
316 CLEAR FLOOD
YES
NO
317 GET CLEAR FLOOD PW
318 GET CRANK PW

FIG. 3

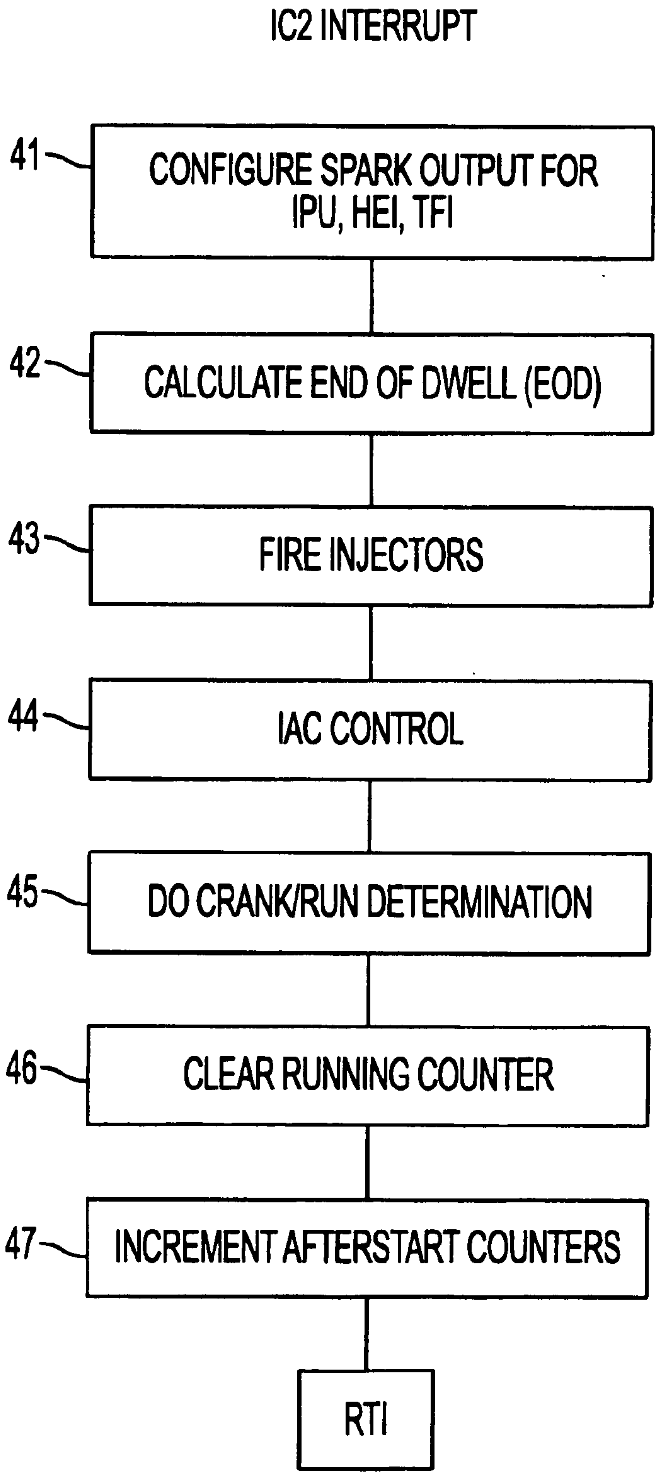

IC2 INTERRUPT
41
CONFIGURE SPARK OUTPUT FOR IPU, HEI, TFI
42
CALCULATE END OF DWELL (EOD)
43
FIRE INJECTORS
44
IAC CONTROL
45
DO CRANK/RUN DETERMINATION
46
CLEAR RUNNING COUNTER
47
INCREMENT AFTERSTART COUNTERS
RTI

FIG. 4

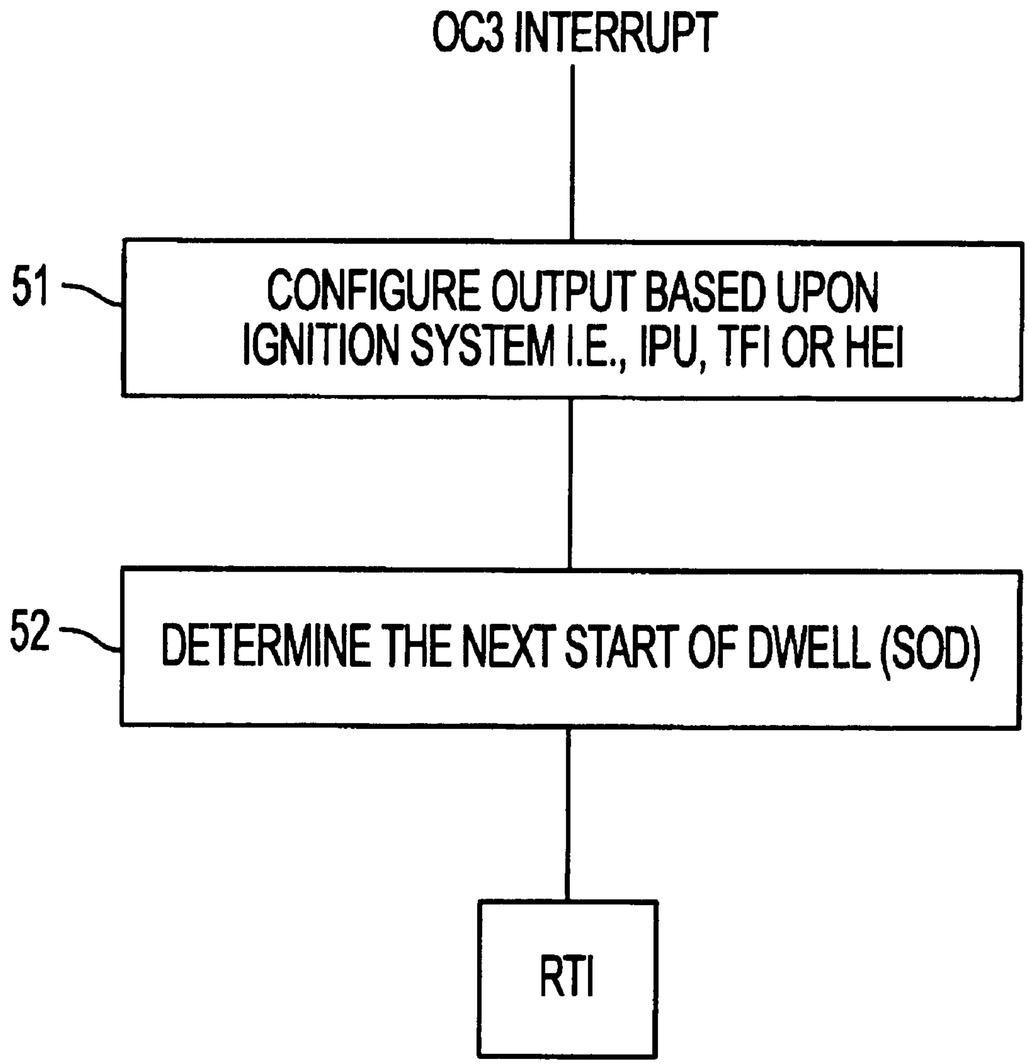

OC3 INTERRUPT
51
CONFIGURE OUTPUT BASED UPON IGNITION SYSTEM I.E., IPU, TFI OR HEI
52
DETERMINE THE NEXT START OF DWELL (SOD)
RTI

FIG. 5

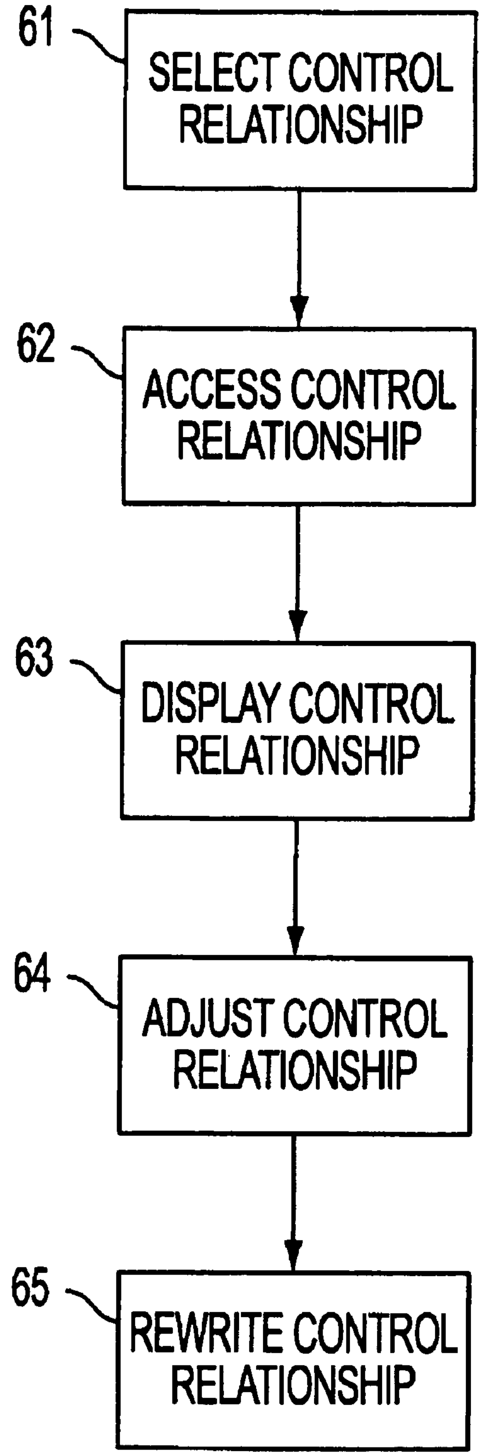

61
SELECT CONTROL RELATIONSHIP
62
ACCESS CONTROL RELATIONSHIP
63
DISPLAY CONTROL RELATIONSHIP
64
ADJUST CONTROL RELATIONSHIP
65
REWRITE CONTROL RELATIONSHIP

FIG. 6

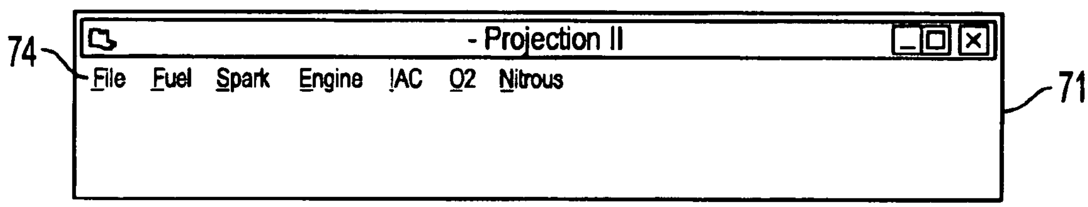
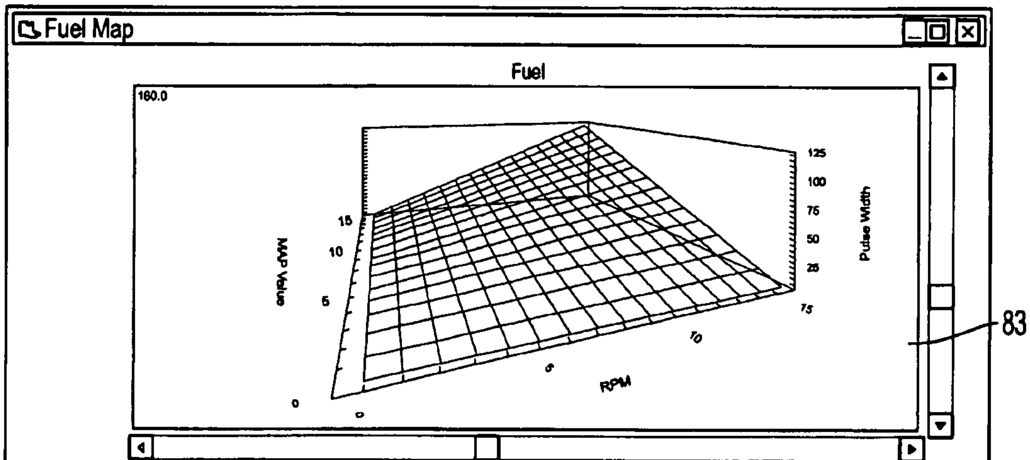


FIG. 7



MAP	500	1000	1500	2000	2500	3000	3500	4000	4500	5000	5500	6000	6500	7000	7500	8000
240	10	18	25	32	40	48	55	62	70	78	85	92	100	108	115	122
224	10	17	24	31	38	45	52	59	66	73	80	87	94	101	108	115
208	10	16	23	30	36	42	49	56	62	68	75	82	88	94	101	108
192	10	16	22	28	34	40	46	52	58	64	70	76	82	88	94	100
176	10	16	21	26	32	38	43	48	54	60	65	70	76	82	87	92
160	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85
144	10	14	19	24	28	32	37	42	46	50	55	60	64	68	73	78
128	10	14	18	22	26	30	34	38	42	46	50	54	58	62	66	70
112	10	14	17	20	24	28	31	34	38	42	45	48	52	56	59	62
96	10	13	16	19	22	25	28	31	34	37	40	43	46	49	52	55
80	10	12	15	18	20	22	25	28	30	32	35	38	40	42	45	48
64	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40
48	10	12	13	14	16	18	19	20	22	24	25	26	28	30	31	32
32	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
16	10	10	11	12	12	12	13	14	14	14	15	16	16	16	17	18
0	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10

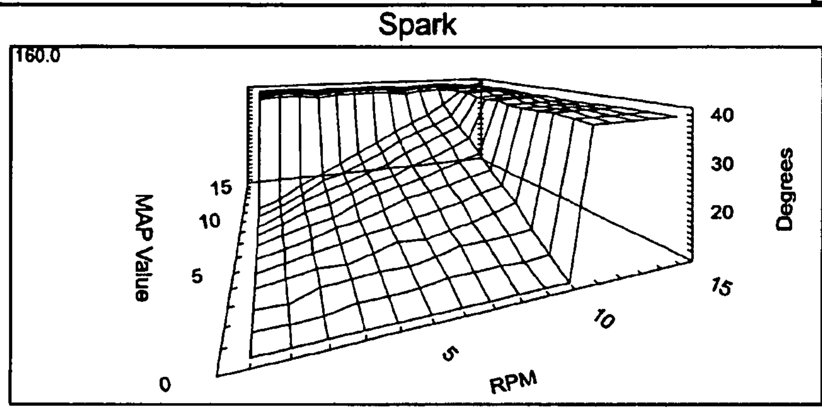
Engine RPM

82

81

FIG. 8

Spark Table



MAP																
240	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40
224	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40
208	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40
192	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40
176	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40
160	12	14	17	20	22	24	27	30	32	34	37	40	40	40	40	40
144	12	14	16	19	21	23	26	28	30	32	34	40	40	40	40	40
128	12	14	16	18	20	22	24	26	28	30	32	40	40	40	40	40
112	12	14	16	17	19	21	22	24	26	28	30	40	40	40	40	40
96	12	14	15	16	18	20	21	22	24	26	27	40	40	40	40	40
80	12	13	14	16	17	18	20	21	22	23	24	40	40	40	40	40
64	12	13	14	15	16	17	18	19	20	21	22	40	40	40	40	40
48	12	13	14	14	15	16	16	17	18	19	20	40	40	40	40	40
32	12	12	13	14	14	14	15	16	16	16	17	40	40	40	40	40
16	12	12	12	13	13	13	14	14	14	14	14	40	40	40	40	40
0	12	12	12	12	12	12	12	12	12	12	12	40	40	40	40	40
	500	1000	1500	2000	2500	3000	3500	4000	4500	5000	5500	6000	6500	7000	7500	8000

FIG. 9

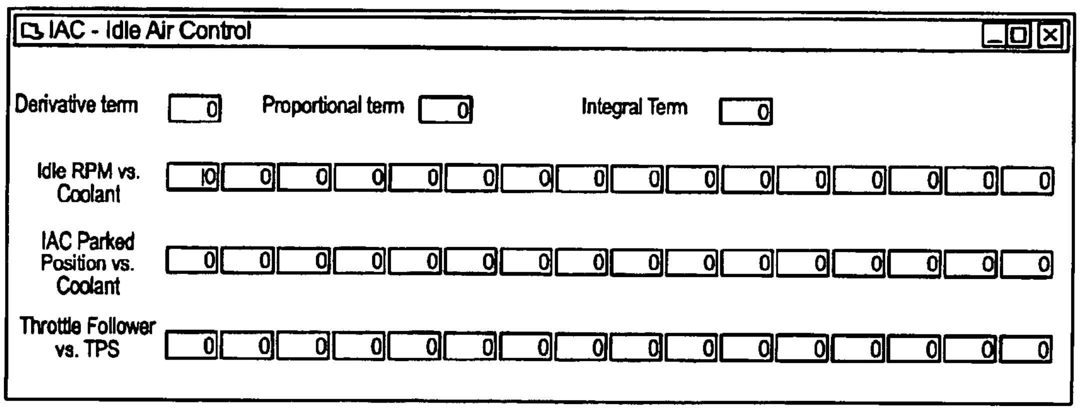

IAC - Idle Air Control
Derivative term
0
Proportional term
0
Integral Term
0
Idle RPM vs. Coolant
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
IAC Parked Position vs. Coolant
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
Throttle Follower vs. TPS
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0

FIG. 10

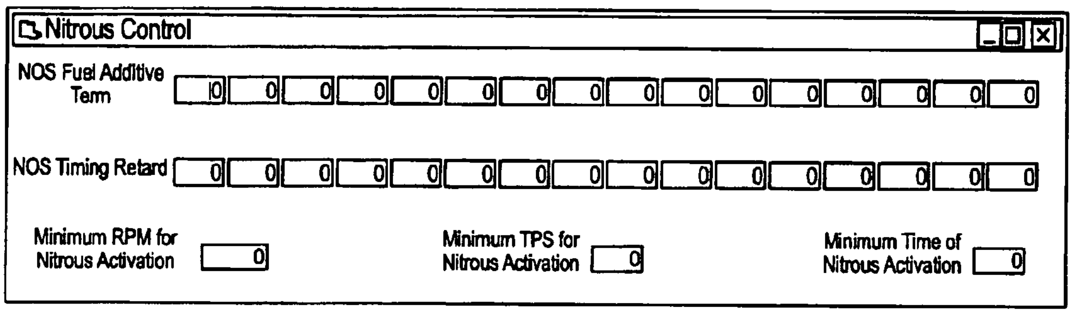

Nitrous Control
NOS Fuel Additive Term
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
NOS Timing Retard
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
Minimum RPM for Nitrous Activation
0
Minimum TPS for Nitrous Activation
0
Minimum Time of Nitrous Activation
0

FIG. 11

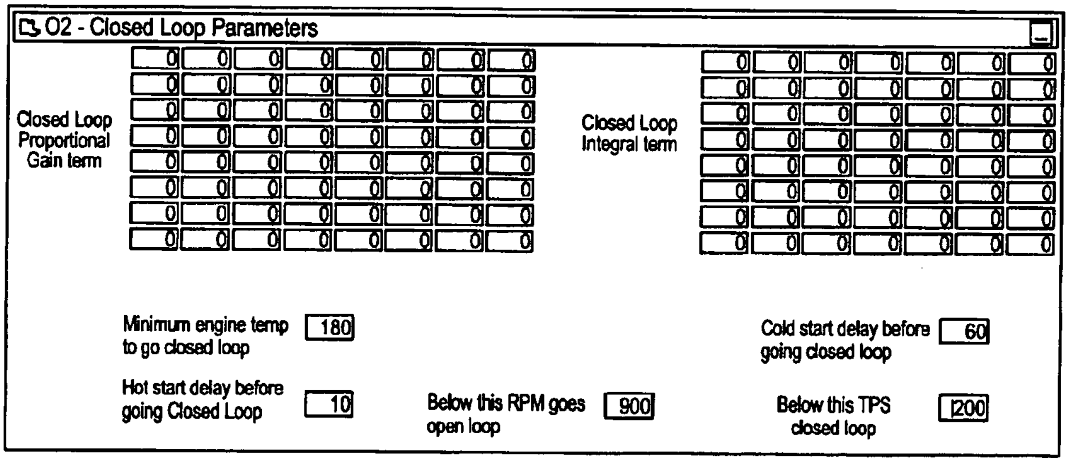

O2 - Closed Loop Parameters
Closed Loop Proportional Gain term
Closed Loop Integral term
Minimum engine temp to go closed loop
180
Cold start delay before going closed loop
60
Hot start delay before going Closed Loop
10
Below this RPM goes open loop
900
Below this TPS closed loop
200

FIG. 12

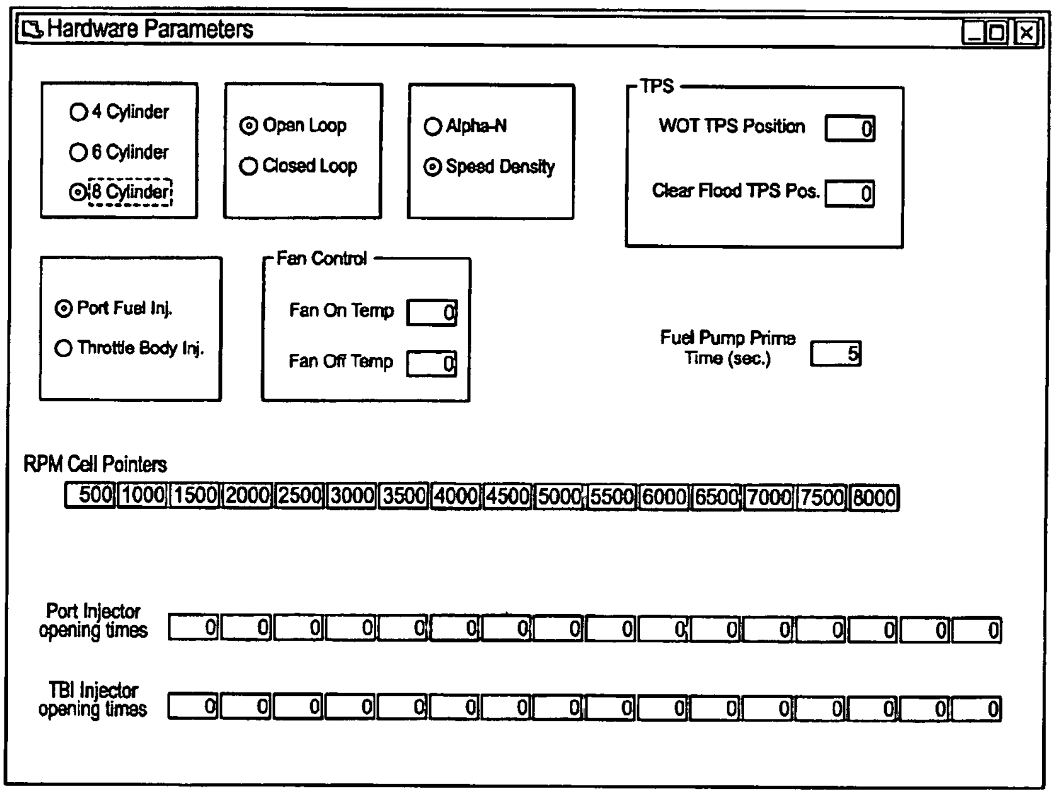

Hardware Parameters
4 Cylinder
6 Cylinder
8 Cylinder
Open Loop
Closed Loop
Alpha-N
Speed Density
TPS
WOT TPS Position
0
Clear Flood TPS Pos.
0
Port Fuel Inj.
Throttle Body Inj.
Fan Control
Fan On Temp
0
Fan Off Temp
0
Fuel Pump Prime Time (sec.)
5
RPM Cell Pointers
500 1000 1500 2000 2500 3000 3500 4000 4500 5000 5500 6000 6500 7000 7500 8000
Port Injector opening times
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
TBI Injector opening times
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0

FIG. 13

SYSTEM AND METHOD FOR REAL-TIME ELECTRONIC ENGINE CONTROL

CROSS REFERENCE TO RELATED APPLICATIONS

This application is based on provisional application Ser. No. 60/163,253, titled "System and Method for Real-Time Electronic Engine Control," filed Nov. 3, 1999.

FIELD OF THE INVENTION

The present invention is directed to electronic control of engines. More specifically, the present invention is directed to a system and method for electronically controlling an engine including the ability to reprogram control variables without interrupting control operation.

BACKGROUND OF THE INVENTION

Electronic control of engines for automotive and related applications is known. Most control schemes involve calculation of controllable variables in real time based upon prestored relationships and inputs from sensors that monitor engine operation. Most control schemes enable control variables to be calculated in both open-loop operation during engine warm-up when engine fluid temperatures necessitate a richer air/fuel ratio, and in closed-loop operation under normal operating conditions when feedback from an oxygen sensor in the engine exhaust is used to monitor the air/fuel ratio. These control schemes typically require time to calculate the control variables.

To reduce calculation time, look-up tables are used to obtain control parameters during engine operation. Initially, it was proposed to employ look-up tables in open-loop control during engine warm-up. A serious problem and limitation of such systems lies in the requirement that the tables be permanently stored in a programmable read-only memory or PROM that is initially programmed at the factory, and that requires removal and replacement to change or reprogram any of the stored control variables. Although such requirement for removal and replacement at a factory service facility or the like has been considered to be acceptable for normal passenger car and light truck applications in view of EPA requirements that critical engine control parameters not be variable outside of an authorized service environment, such schemes are unacceptable for racing and other off-road applications, and in development and test environments. In applications of these types, it is necessary that the control variables be readily, individually and selectively reprogrammable by a technician or other operator at the site.

An engine control system that utilizes look-up tables stored in an EEPROM during both wann-up and normal operation was developed. An external programming unit enabled system memory to be reprogrammed without requiring removal of the memory package, to accommodate specific vehicle conditions, such as fuel quality, climate, etc. Nevertheless, control variables could not be adjusted during actual engine operation.

Subsequent developments have enabled control variables to be adjusted during engine operation. Nevertheless, those adjustments do not immediately take effect and control does not take place when adjustments are being made. Rather, when a user is making adjustments to a particular control variable, the control relationship using the particular control variable is temporarily disabled. This leads to loss of responsiveness in the control process and to a potential dangerous situation.

SUMMARY OF THE INVENTION

It is an object of the present invention to overcome these and other drawbacks with conventional engine control systems.

It is another object of the present invention to provide a system and method for electronic control of engine operation that enables real-time reprogrammability of engine control relationships without disabling control functionality.

It is another object of the present invention to provide a system and method for electronic control of engine operation that enables reprogramming of engine control relationships and the control algorithm.

Another object of the invention is to provide a method and system for electronic engine control in which the engine control variables may be readily and selectively varied in real time without disabling control functionality, so that the operator may readily observe the effects of parameter variation and make any desired further adjustments without necessitating removal of table memory or other electronic circuitry.

Another object of the present invention is to provide a system and method for electronic engine control in which control variable tables are displayed to an operator to facilitate selective variation of the control relationships.

According to one embodiment, an engine control system for providing electronic control signals to an engine is disclosed. The system comprises one or more sensors that produce input signals in response to engine operating conditions and one or more control apparatus, responsive to the electronic control signals, that control engine operating conditions. An electronic control unit produces the electronic control signals in response to the input signals based on a set of defined relationships and a-user controller enables viewing and modifying of the set of defined relationships. The electronic control unit comprises a unique memory structure that enables selective rewriting of the set of defined relationships in real-time without interrupting control operation by the user controller.

According to another embodiment, a method of controlling an engine is disclosed. The method comprises providing one or more input signals in response to engine operating conditions and producing electronic control signals in response to the input signals based on a set of defined relationships. The electronic control signals are used by one or more control apparatus that control engine operating conditions. The defined relationships may be selectively modified in real-time without interrupting the production of electronic control signals.

Other features and advantages of the present invention will be apparent to one of ordinary skill in the art upon reviewing the detailed description of the present invention.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a schematic block diagram of an electronic engine control system according to one embodiment of the present invention.

FIG. 2 is a schematic block diagram of an engine control unit according to one embodiment of the present invention.

FIG. 3 is a flow chart of a method for controlling an engine according to one embodiment of the present invention.

FIG. 4 is a flow chart of an input capture routine according to one embodiment of the present invention.

FIG. 5 is a flow chart of an output compare routine according to one embodiment of the present invention.

FIG. 6 is a flow chart of a method for adjusting an engine control relationship according to one embodiment of the present invention.

FIG. 7 shows an exemplary graphical user interface used to select a control relationship in conjunction with the method of FIG. 6.

FIG. 8 shows an exemplary graphical user interface used to display and adjust the fuel map.

FIG. 9 shows an exemplary graphical user interface used to display and adjust the spark table.

FIG. 10 shows an exemplary graphical user interface used to display and adjust the idle air control relationship.

FIG. 11 shows an exemplary graphical user interface used to display and adjust the nitrous oxide control relationship.

FIG. 12 shows an exemplary graphical user interface used to display and adjust various closed loop parameters.

FIG. 13 shows an exemplary graphical user interface used to display and adjust various hardware parameters.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

A method and system for controlling an engine is disclosed. According to one embodiment, the present invention advantageously permits a user to modify the defined relationships that are used to control the engine. Significantly, the method and system of the present invention enable those control relationships to be adjusted on-the-fly without interrupting the control operation in contrast to conventional engine control units.

FIG. 1 illustrates an engine control system in accordance with one embodiment of the invention. The engine control system of FIG. 1 comprises an internal combustion engine **10**, an engine control unit **13** and a user controller **14**. Internal combustion engine **10** comprises a number of control mechanisms **11** that are responsive to control signals developed by engine control unit (ECU) **13**, and a number of sensors **12** that develop analog and digital signals for use by ECU **13**.

ECU **13** is shown and will be explained in more detail in conjunction with FIG. 2. Briefly, ECU **13** receives analog and digital input signals from sensors **12** and in response provides control signals to control mechanisms **11**. ECU develops these control signals based on a set of predefined relationships that are stored therein. According to one embodiment, ECU **13** communicates with user controller **14**.

User controller **14** communicates with and is operative to reprogram ECU **13**. According to one embodiment, user controller **14** comprises a personal computer that communicates with ECU through a standard modem. According to one specific embodiment, user controller **14** comprises a laptop computer including a display screen to view engine control relationships (for example, tables of control variables) and a keyboard and mouse that is used to modify those control relationships.

FIG. 2 depicts ECU **13** in more detail. ECU **13** comprises micro-controller **20**, nonvolatile memory **21**, flash memory **22**, and serial communications port **23**. ECU **23** is responsive to a number of sensors that produce analog inputs and a number of digital inputs.

The analog inputs include inputs from throttle position sensor **240** (indicates the degree of rotation of the engine throttle under control of the operator), exhaust gas oxygen sensor **241** (positioned in the engine exhaust and is used to determine the richness and leanness of the air/fuel mixture entering the cylinders), manifold absolute pressure sensor **242** (indicates air pressure within the engine air intake manifold, which is indicative of engine load), slew fuel input **243** (enables rapid user control of the fuel supply to determine what effect more/less fuel has on engine operation at a given load/RPM point), manifold air temperature sensor **244**, slew spark input **245** (enables rapid user control of the spark timing to determine what effect more/less spark has on engine operation at a given load/RPM point), engine coolant temperature sensor **246** and battery voltage input **247** (reduced voltage input to micro-controller **20** that is indicative of battery voltage —e.g. a 4.8 V input represents 16 V at the battery). Each of these sensors may comprise appropriate conventional sensors.

The digital inputs include a park/neutral signal **250** (indicates current drive status of vehicle to prevent engine from being started in gear), vehicle speed signal **251** (determines vehicle speed based on drive shaft rotation), ac compressor request signal **252** (indicates ac compressor is on and therefore engine load has increased), REF/PIP signal **253** (signal from OE distributor module indicates spark reference and provides system trigger for GMs and Fords respectively), NOS enable signal **254** (indicates the Nitrous oxide enrichment has been selected), IPU input **255** (magnetic input to be used as a spark reference for crank trigger wheel configurations), knock input **256** (output from a knock sensor), coil input **257** (input from ignition coil primary used as an alternate system trigger to REF/PIP and IPU), switched power input **258** (input indicating that the key to the engine has been turned on) and mode select input **259** (signal indicating whether micro-controller **20** should operate in normal mode or programmed mode).

In response to these analog and digital inputs, ECU **13** produces a number of control signals. Specifically, ECU **13** produces a stepper motor driver signal **260** (used to control the idle air stepper motor (IAC) coupled to the manifold air bypass of engine for adjusting idle speed); fuel injector driver signals **261** (pulsed signals of controlled time duration used to control a plurality of fuel injectors for injecting desired quantities of fuel to the air manifold adjacent to the cylinder intake ports of the engine); electronic ignition control signal **262** (used to control spark timing of the engine); bypass/aux control signal **263** (in aux mode may be used, e.g., for controlling a plurality of LEDs on an operator console or panel to indicate any fault or warning conditions to the operator; in bypass mode may be used to control the function of certain ignition modules, e.g., GM ignition modules); fuel pump control signal **264** (used to control a fuel pump to feed fuel from a tank or supply (not shown) to the injectors of engine); cooling fan control signal **265** (used to control a fan to cool fluid in the radiator based on engine temperature); CD ignition control signal **266** (used to control firing of an after-market CD and thus timing of the engine) and NOS control signal **267** (used to control a solenoid used to provide NOS injection).

Microcontroller **20** receives the various analog inputs (**240–247**) and digital inputs (**250–259**) and generates the control signals (**260–267**) using control relationships stored in nonvolatile memory **21**. According to one embodiment, microcontroller **20** comprises any suitable microprocessor based controller. According to one specific embodiment, microcontroller **20** comprises a Motorola HC68HC11 microprocessor. Other microprocessors are possible.

According to one embodiment, the present invention comprises two separate memories. Nonvolatile memory **21** is used to store the control relationships that are used to develop control signals in conjunction with the various analog and digital inputs. Flash memory **22** is used to store the executable code for microcontroller **20**.

Nonvolatile memory 21 employs a two tier memory structure that comprises a working storage area and a non-volatile storage area. The working storage area comprises a read/write memory that is used to store the control relationships during engine operation. According to one embodiment, the working storage area comprises memory that can be written and rewritten in real-time so that control operation is not interrupted even while the control relationships are being modified. According to one embodiment, working storage area comprises RAM. The non-volatile storage area comprises memory that stores the control relationships when power is lost to microcontroller 20. According to one embodiment, the non-volatile storage area comprises EEPROM. In one particular embodiment, both working storage area and non-volatile storage area comprise a single non-volatile static RAM chip. Such a chip comprises both RAM and a backup non-volatile EEPROM for storing information when power is lost.

Flash memory 22 comprises a memory that is used to store the executable code for microcontroller 20. As discussed above, in conventional microcontrollers it was not possible to rewrite the executable code. Rather, the memory holding the executable code, typically some type of ROM, had to be swapped with a memory having the new executable code "burned in." In contrast, flash memory 22 comprises a writeable, non-volatile memory. According to one embodiment, flash memory 22 comprises a flash EPROM. Thus, executable code for the microcontroller can be rewritten as necessary.

Serial communications port 23 enables microcontroller 20 to communicate with other devices. According to one embodiment, user controller 14 communicates with microcontroller 20 through serial communications port 23. Thus, serial communications port 23 is the communications port through which the control relationships and executable code for microcontroller 20 are rewritten. According to one embodiment, serial communications port 23 enables communication of microcontroller 20 with a remote device through a modem. According to one specific embodiment, serial communications port 23 comprises an RS232 communications port.

FIGS. 3, 4, and 5 depict flowcharts showing a method of controlling an engine according to one embodiment of the present invention. According to one embodiment, the method of controlling an engine comprises one or more computer programs that control an engine control unit such as ECU 13 and specifically microcontroller 20. FIG. 3 is a flowchart of the main program, FIG. 4 is a flowchart for an input capture routine, and FIG. 5 is a flowchart for an output compare routine. Each of FIGS. 3, 4 and 5 are explained in detail below.

The method of FIG. 3 begins in step 31 by monitoring ECU 13 to determine if the ECU is operating properly. The method comprises a safety mechanism that will reset the ECU (and the engine) if it is not operating properly. According to one embodiment, the safety mechanism comprises a software module that determines whether or not a set of instructions has been received. If the set of instructions has been received, it is determined that the ECU is operating properly and there is no need to shut the engine down. If the instructions are not received, it is determined that the engine is not operating properly and the ECU is reset and the engine is shut down.

In step 32, the method accomplishes a number of polled real-time chores. The polled real time chores comprise a set of operations that are accomplished at regular intervals. According to one embodiment, the program depicted in FIG. 3 comprises real-time chores that are accomplished at 4, 8, 16, 32, and 64 ms. Other intervals are possible. According to one embodiment, the polled real-time chores at each interval comprise separate subroutines. According to one embodiment, the following chores comprise real-time polled chores. Other chores may be added. Moreover, the chores outlined below may also be moved into any of the other routines, e.g., the main program or the routines of FIGS. 4 and 5. According to one embodiment, readings from throttle position sensor 240, exhaust gas oxygen sensor 241, manifold absolute pressure sensor 242, slew fuel sensor 243, manifold air temperature sensor 244, slew spark sensor 245, engine coolant temperature sensor 246 and battery voltage sensor 247 are checked, and their values are converted from analog values to digital values in real-time at step 32.

The running counter comprises a counter that is used to determine whether or not the engine being controlled is operating properly. The running counter is monitored and incremented during the regular intervals in the main program and cleared during the input capture routine (explained in conjunction with FIG. 4 below). Therefore, if the running counter rises above a particular value it provides an indication that the input capture routine (that is initiated based on crankshaft rotation) has not been initiated and accordingly, that the engine has stopped. According to one embodiment, the running counter comprises a software module that is monitored and incremented at regular intervals. According to this embodiment, if the running counter has reached a value of 128, it is an indication that the engine is not running properly, and engine control unit 13 is reset.

According to another embodiment, the idle air control IAC) stepper motor is adjusted as one of the real-time chores. The IAC stepper motor 260 is part of a PID control loop (see step 44 of FIG. 4) that maintains engine idle speed at a programmed RPM level. Specifically, engine speed and the rate and direction of change of engine speed are monitored and adjustments to IAC stepper motor position are made to either increase or decrease bypass air flow to and thus to increase or decrease engine idle speed, respectively.

According to another embodiment, the rate of change of throttle position is calculated as one of the real-time chores. The rate of change in throttle position is used to determine whether or not transient fueling is necessary. In a simultaneous double-fire engine fuel delivery system, fuel is delivered once per crankshaft revolution. Injector pulses are synchronous with the trigger input from the engine tachometer. If the throttle is opened abruptly, synchronous fuel delivery is typically insufficient, and the engine may hesitate or backfire. To overcome this problem, additional fuel pulses are delivered between the synchronous pulses. This is termed asynchronous fueling in the art because the additional fuel is not synchronized with the tachometer signal. When the engine is cold, transient response is greatly improved by the addition of asynchronous fuel, while at hotter engine temperatures asynchronous fuel tends to over fuel the engine. According to one embodiment, a defined relationship between the rate of change of throttle position and engine coolant temperature is used to determine whether or not asynchronous fueling is appropriate.

According to another embodiment, the rate of change of manifold pressure is a real-time chore and is used to determine whether or not transient fueling is required. According to one embodiment, similar to explained above, a defined relationship between the rate of change of manifold pressure and engine coolant temperature is used to determine whether or not synchronous fueling is appropriate.

According to another embodiment, the knock signal **256** is also monitored. As shown in FIG. **2**, the knock sensor comprises a separate digital input to the ECU. According to one embodiment, each time a knock is detected, a programed amount of timing is removed.

According to another embodiment, a number of control parameters are looked up as real-time chores. According to one embodiment, these control parameters are based on the current operating conditions of the engine. One example of a control parameter that is looked up as a part of the real-time chores is the park position for the IAC stepper motor.

Returning to FIG. **3**, in step **33**, x-axis pointers are calculated for the control matrices. According to one embodiment, defined relationships are used in conjunction with sensor readings to control engine performance. For example, in conjunction with the system shown in FIGS. **1** and **2**, for every possible reading of manifold absolute pressure sensor **244** and vehicle speed sensor **251**, microcontroller **20** provides a particular control signal to fuel injector drivers **261**. The same is true for the other sensors and control mechanisms shown in FIG. **2**. These relationships between the sensor readings and the control signals can be expressed in a number of different ways including in a matrix of numbers, and in a graph. In either case, it may be desirable to view the relationship in more detail in a particular area. Therefore, in step **33**, x-axis pointers for the relationship may be set. Thus, if one area of the relationship is of particular interest, a user may set several pointers in that area, effectively giving more resolution to the relationship within that area. According to one embodiment, x-axis pointers may be set for each control relationship. According to another embodiment, x-axis pointers may be set for the fuel map (used to control fuel injector drivers **261**) and the spark map (used to control electronic ignition controller **262**).

In step **34**, the spark advance is calculated. According to one embodiment, the spark advance is calculated using a defined relationship (as explained above) based on the RPM reading from vehicle speed sensor **251** and a load reading. The load reading may comprise either a reading from manifold absolute pressure sensor **242**, or throttle position sensor **240**. These two factors, determine a spark advance from the defined relationship.

In step **35**, cooling fan **265** is controlled. According to one embodiment, cooling fan **265** is controlled using a defined relationship based on present readings from engine temperature sensor **246**. According to one embodiment, if the engine temperature is greater than a certain threshold, the cooling fan is activated.

In step **36**, fuel pump **264** is controlled. According to one embodiment, fuel pump **264** remains on, as long as the engine is cranking. According to a specific embodiment, the running counter (as explained above) is monitored to determine whether or not the engine is cranking. If the running counter is less than a predetermined number, the engine is cranking, and the fuel pump remains activated. According to another embodiment, if the engine continues to crank for more than some predetermined amount of time, the fuel pump is turned off. According to a specific embodiment, if the engine continues to crank for more than 10 seconds, the fuel pump is turned off.

In step **37**, the injector opening time is corrected based on a defined relationship. The opening time for fuel injectors may vary based on the battery voltage. Therefore, in step **37**, the injector opening time is controlled based on the battery voltage. As explained above, the present invention uses a number of defined relationships in conjunction with sensor readings to control engine performance. In the case of the injector opening time, according to one embodiment, the battery voltage is determined from battery voltage sensor **247**, and the particular injector opening time that is appropriate for that battery voltage is determined in step **37** and used to control fuel injector drivers **261**. According to another embodiment, a correction factor for injector opening time is determined based on the battery voltage and used to control fuel injector drivers **261**.

In step **38**, an engine control unit communicates with a programmer to adjust engine control relationships. According to one embodiment, the method of FIG. **3** operates in conjunction with ECU **13** shown in FIGS. **1** and **2**. In this embodiment, when user controller **14** communicates with ECU **13**, control parameters are read from and written to non-volatile static memory **22**. According to one particular embodiment, data is moved in and out of memory **22** in blocks. Thus, if a user desires to adjust the responsiveness of the engine to a change in manifold absolute pressure, the entire fuel map may be pulled from memory **22** and sent to user controller **14** through RS232 communication port **23**. A user can then view the map at user controller and make appropriate adjustments.

In step **39**, a determination is made whether the engine is running in crank mode or run mode. Depending on whether the engine is operating in run or crank mode, a different set of operations is accomplished. According to one embodiment, it is determined that the engine is operating in run mode if it has been operating at greater than 350 rpm for a predetermined number of cycles. According to a specific embodiment, the reading from engine speed sensor **251** is used to determine whether the engine is operating in run or crank mode. If in step **39**, it is determined that the engine is operating in run mode, operations **310** to **313** are accomplished. If in step **39** it is determined that the engine is operating in crank mode, operations **314** to **318** are accomplished.

In step **310**, the O_2 subroutine is accomplished. In the O_2 subroutine, the O_2 sensor is checked to determine whether or not the air fuel mixture needs adjustment. According to one embodiment, if air fuel mixture needs to be adjusted, a PI control loop is used to make the necessary adjustments based on a defined relationship between engine speed and load. Such adjustments are known in the art.

In step **311**, the nitrous oxide subroutine is called. The nitrous oxide subroutine monitors the nitrous enable line **254** shown in FIG. **2**, to determine whether or not nitrous oxide is to be added to the fuel mixture. If the status of nitrous enable line **254** indicates the nitrous oxide is to be added to the fuel mixture, and minimum throttle position, time and RPM thresholds have been met, it is determined that it is appropriate to add nitrous. If nitrous is added, appropriate adjustments to fuel and timing are made based on the RPM reading of vehicle speed sensor **251** and a defined relationship.

In step **312**, after start subroutine is accomplished. After start enrichment is intended to help overcome the initial start-up frictions and viscosities present in a cold engine, as well as to compensate for hot soak fuel vaporization in the fuel system of hot engines. The after start subroutine is used to add additional fuel to the engine in the time period following ignition. According to one embodiment, a counter is maintained to determine whether or not after start enrichment is appropriate. The after start counter is incremented in

the input capture subroutine shown in FIG. 4 and thus provides an indication of the number of crankshaft revolutions that have occurred. According to one embodiment, if the after start enrichment is appropriate, an appropriate amount of fuel to be added is determined based on a reading of engine speed sensor **251** and a defined relationship. The additional fuel to be added is gradually decayed based on a defined relationship between the engine coolant temperature and the counter.

In step **313**, the fuel injector pulse width subroutine is accomplished. Based on a defined relationship between the manifold absolute pressure and engine speed, the fuel injector pulse width is adjusted. According to one embodiment, a look up table is used to store fuel injector pulse width. According to one specific embodiment, manifold absolute pressure sensor **244** and vehicle speed sensor **251** are read and used to determine the appropriate fuel injector pulse width under run conditions.

If it is determined that the engine is operating in crank mode in step **39**, then, in step **314** an O_2 delay is determined. According to one embodiment, the O_2 delay is determined based on initial coolant temperature and a defined relationship. As explained previously, the present invention uses a number of defined relationships in conjunction with sensor readings to control engine performance. According to one embodiment, O_2 delay is determined based on readings from engine coolant temperature sensor **246**.

In step **315**, the park position for IAC stepper motor is determined. According to one embodiment, the park position is determined based on initial coolant temperature and a defined relationship. As explained previously, the present invention uses a number of defined relationships in conjunction with sensor readings to control engine performance. In the case of the park position, according to one embodiment, the park position is determined based on readings from engine coolant temperature sensor **246**.

In step **316**, it is determined whether or not a flood has occurred. If a flood has occurred in step **317**, injector pulsing is stopped. According to one embodiment, readings from throttle position sensor **240** are used to determine whether or not a flood has occurred. If throttle position exceeds a certain threshold, it is determined a flood has occurred and a clear flood mode is initiated. In the clear flood mode, among other things, injector pulsing is stopped.

If it is determined that no flood has occurred, in step **318**, the crank pulse width for the fuel injector is determined. According to one embodiment, the crank pulse width for the fuel injectors is determined based on a predefined relationship with engine coolant temperature. According to one embodiment, a look up table is used to store fuel injector pulse width under cranking conditions. According to one specific embodiment, engine coolant temperature sensor **246** is read and used to determine the appropriate fuel injector pulse width.

After either the run time or crank time chores have been accomplished, the operation of the main program returns to step **31**.

FIG. 4 is a flow chart showing a method of capturing input for a subroutine of the main program for controlling ECU **13** shown in FIGS. **1** and **2**. The input capture method shown in FIG. **4** is initiated based on crankshaft rotation. According to one embodiment, the method of FIG. **4** is initiated after the crankshaft rotates 90°. Other embodiments are possible.

The input capture method of FIG. **4** begins with Step **41** where the spark output configuration is determined. The spark output configuration depends on the type of engine that is being controlled. The engine control unit shown in FIG. **2** may be used to control a number of different engines. According to one embodiment, ECU **13** is used to control an engine with an inductive pickup ignition. According to other embodiments, ECU **13** is used to control other engine types.

In step **42** the end of dwell (EOD) is calculated. The end of dwell is calculated in a manner that is known in the art. According to one embodiment, the start of dwell (SOD) is calculated in the output interrupt subroutine shown in FIG. **5**.

In step **43** the injectors are fired. According to one embodiment, the manner in which the injectors are fired depends on, at least, the mode of operation of ECU **13** and the number of cylinders. According to one embodiment, the ECU may operate in conjunction with a port fuel injection system or a throttle body fuel injection system and in conjunction with engines having any number of cylinders. Thus, depending on these two factors, a different set of signals are generated by microcontroller **20** and are used to control fuel injector drivers **261**.

In step **44**, idle air stepper motor is controlled. The IAC stepper motor is used to control the amount of air in the fuel air mixture and thus control the idle speed. According to one embodiment, a PID (proportional integral differential) calculation is used to determine the IAC control. According to one embodiment, the PID calculation is based on the difference between the desired and actual idle speed (as measured by vehicle speed sensor **251**).

In Step **45** the determination is made as to whether the engine is operating in crank mode or run mode. According to one embodiment, if the engine is operating at greater than 350 RPMs for more than a predetermined number of cycles, the engine is operating in run mode. Otherwise, it is determined that the engine is operating in crank mode.

In Step **46** the running counter is cleared. As explained above, the running counter holds a count that is used to determine whether the engine and the ECU are operating properly. Operation of the input capture subroutine indicates that the engine and the ECU are operating properly. Thus, in step **46** the running counter is cleared. As explained above, according to one embodiment, the running counter comprises a software module that is incremented every four milliseconds.

In Step **47** the after start counter is incremented. The after start counters are used to determine whether or not the engine is operating in an after start mode. For a period of time after an engine is started a richer fuel air mixture is used. The after start counter begins at zero and is incremented each time through the input capture subroutine. When the input counter reaches a certain threshold, it is determined that the richer fuel air mixture is no longer necessary. That is, the engine is no longer operating in an after start mode.

FIG. **5** shows a flowchart depicting an output compare subroutine. The output compare subroutine is initiated after each input capture subroutine. Other embodiments are possible. According to one embodiment the input capture subroutine shown in FIG. **4** is used to develop inputs that are used in the output compare subroutine of FIG. **5**.

The output compare subroutine shown in FIG. **5** begins at step **51** by determining the type of ignition system that is being used. As explained in conjunction with FIG. **4**, step **41**, the ECU may be used in conjunction with a number of different engine configurations and ignition systems. Each different configuration generally requires a different form of output. Thus, in Step **51** the output is configured for the

proper ignition system. According to one embodiment the ECU is used in conjunction with an inductive pickup ignition system.

In Step **52** the start of dwell (SOD) is determined. The start of dwell is determined using the inputs developed in the input capture subroutine shown in FIG. **4**. The start of dwell is determined in a manner that is known in the art.

FIG. **6** is a flowchart showing a method for adjusting engine control relationships according to another embodiment of the present invention. According to one embodiment, the engine control relationships are adjusted by a user through a personal computer. The method will be explained in conjunction with the method and system shown in FIGS. **1**–**5**. In that system, as explained above, user controller **14** is provided to accomplish modification of the control relationships.

Before the method begins, a number of engine parameters are set. The method and system of the present invention is useful in conjunction with a number of different engine types that have different specifications. According to one embodiment, these specifications such as the number of cylinders, and whether the engine uses throttle body fuel injection or port fuel injection are selected before control begins.

The method begins in step **61** with selection of a control parameter for adjustment. According to one embodiment, a user may select any of a plurality of control relationships for adjustment. These control relationships are generally known in the art and are explained briefly below.

The fuel relationship controls the injector pulse width under run conditions based on manifold absolute pressure and engine speed. According to one embodiment, this relationship is utilized at step **313** of the control method shown in FIG. **3**.

The spark relationship controls the spark timing based on engine speed and engine load. Engine load may be measured by manifold absolute pressure or by throttle position. According to one embodiment, the spark relationship is utilized at step **34**.

At least two relationships are used to control the idle that may be chosen in step **62**. The idle speed relationship controls the speed of the idle through control of IAC stepper motor and depends on engine coolant temperature. According to one embodiment, the idle speed relationship is utilized in step **44** of FIG. 4. The idle park position relationship controls the position in which the idle is parked and depends on engine coolant temperature. According to one embodiment, the idle park position relationship is utilized in step **315** of FIG. **3**.

The throttle follower relationship allows a user to monitor the throttle position and idle bypass air of the engine, and to set the minimum limit of the bypass air. The purpose of the throttle follower relationship is to back the idle control mechanism away from its stop at the fully closed position, thereby leaking more air into the intake manifold at off-idle speeds to keep it from smothering the engine during rapid deceleration.

A number of acceleration enrichment relationships control whether or not additional fuel should be added during acceleration condition. According to one embodiment, acceleration enrichment is expressed as additional pulse width to be added to both synchronous or asynchronous pulse widths resulting from the base fuel relationship. Acceleration enrichment relationships depend on: 1) the rate of change of the throttle position; 2) coolant temperature; 3) the throttle position 4) the rate of change of manifold absolute pressure, 5) a decay rate factor and 6) manifold pressure acceleration compensation as a function of coolant temperature.

The after start enrichment relationship controls the amount of after start fuel to be added to the engine and depends on coolant temperature. The after start enrichment relationship relates percent enrichment to engine coolant temperature. The enrichment percentage is added to the base pulse width from the base fuel map. The after start hold off relationship controls when after start enrichment should begin and depends on the number of engine revolutions (as measured using, e.g., an after start counter) and engine coolant temperature. The amount of enrichment decays at a rate specified in an after start enrichment decay relationship. The after start enrichment decay relationship controls the rate at which fuel enrichment is to be diminished and depends on engine coolant temperature and the number of revolutions that have occurred. According to one embodiment, the after start relationships are utilized in step **312** of FIG. **3**.

The warm-up enrichment relationship controls whether or not fuel is to be added synchronously while the engine is warming up and depends on engine coolant temperature. The relationship determines an enrichment factor that increases the fuel delivered to the engine during warm-up based on engine coolant temperature.

The air temperature enrichment relationship controls whether or not fuel is to be added synchronously and depends on air temperature into the engine. According to one embodiment, the reading of manifold air temperature sensor **244** is utilized to determine whether or not air temperature enrichment is appropriate.

The cranking pulse width relationship controls the fuel injector pulse width under cranking conditions. The injector pulse width under cranking conditions depends on engine coolant temperature. According to one embodiment, this relationship is utilized at step **318** of the control method shown in FIG. **3**.

According to one embodiment, a graphical user interface (GUI) is provided to enable the user to select a particular control relationship to modify. The GUI may provide any of a number of known mechanisms such as text boxes and dialog boxes to enable a user to select or enter a particular control relationship to be adjusted. An exemplary GUI that may be used to select a control relationship to modify is shown in FIG. **7**. FIG. **7** depicts a selection GUI **71**. Selection GUI **71** comprises a number of pull down menus **74** that may be used to select various ones of the control relationships for displaying and adjusting.

In step **62**, the control relationship is accessed. According to one embodiment, the method for adjusting the control relationship operates in conjunction with the system of FIGS. **1** and **2** and user controller **14** communicates with engine control unit **13**, using a modem and serial communication port **23**, to access the selected control relationship. According to this embodiment, control relationships are stored in nonvolatile static memory **21**. As explained above, nonvolatile static memory **21** advantageously enables transfer of data in and out in blocks such that the control relationship may be quickly downloaded to user controller **14** over a modem.

In step **63**, the control relationship is displayed to the user. The control relationships vary in complexity. Some, such as the fuel relationship comprise a look-up table that is addressed using the appropriate parameters (manifold absolute pressure and engine speed in the case of the fuel

relationship). According to another embodiment, a two-dimensional look-up table may be depicted as a three dimensional map. Other control relationships may comprise a one dimensional relationship or a single value. According to one embodiment, user controller **14** is used to display the control relationship as a table and/or a graph and/or a parameter as appropriate.

One example of the display of a fuel relationship is shown in FIG. **8**. FIG. **8** shows the fuel relationship **81** as a matrix or map of numbers **82**. This fuel map display comprises a display window having a matrix of numeric parameters that form the ECU's base fuel map. The rows correspond to manifold absolute pressure and the columns to engine speed in RPM.

FIG. **8** also shows the fuel relationship as a three dimensional graph **83**. The three dimensional plot of the base fuel map is useful for identifying severe discontinuities or irregularities in the base fuel map that may otherwise go unnoticed in the numeric table. The display of other relationships is similar to the display of the fuel relationship. FIGS. **9–13** show GUIs that are used to control other exemplary relationships such as the spark table (FIG. **9**), IAC (FIG. **10**), nitrous oxide boost (FIG. **11**), closed loop parameters (FIG. **12**), and hardware parameters (FIG. **13**).

In step **64**, the selected control relationship is adjusted. According to one embodiment, for use in conjunction with the display of the relationship as a map, a mouse is used to select one of the values in the map in a manner that is known in the art. Once the value is selected, the up and down arrow keys on a keyboard may be used to adjust the value. Alternatively, the user may simply type a new value over the existing value. According to another embodiment, for use in conjunction with the display of the relationship as a graph, a mouse is used to select and hold a point on the graph. Once selected the point on the graph may be physically raised or lowered using the mouse. Alternatively, once the point on the map is selected, the up and down arrow keys on a keyboard may be used to adjust the value. Other methods of adjusting a value are possible.

In steps **65**, the adjustments are rewritten to memory in the controller and are available for use by the controller in real-time. According to one embodiment, when a user uses the mouse or keyboard arrows to adjust a control relationship, that adjustment is immediately communicated to the engine control unit and written over the existing control relationship. Thus, those adjustments are advantageously made available for use by the controller in real-time without any control disabling in contrast to conventional control schemes. According to one embodiment, this is made possible by the provision of nonvolatile static memory **21** shown in FIG. **2**. The end result is that the effect of the adjustments are felt in real time in the vehicle.

The invention has been described in connection with particular embodiments. These embodiments are intended to be illustrative only. It will be appreciated by those skilled in the art that modifications may be made to these preferred embodiments without departing from the scope of the invention as defined by the appended claims.

What is claimed is:

1. An engine control system for providing electronic control signals to an engine comprising:

one or more sensors for producing input signals in response to engine operating conditions;

one or more control apparatus responsive to the electronic control signals and operative to control engine operating conditions;

an electronic control unit operative to produce the electronic control signals in response to the input signals based on a set of defined relationships, and comprising a memory, the memory comprising:

a working storage area operative to store the set of defined relationships during operation of the electronic control unit, and

a second storage area operative to store the set of defined relationships when the electronic control unit loses power;

a user controller permitting viewing and modifying the set of defined relationships;

wherein the electronic control unit and the user controller enable selective rewriting of the set of defined relationships in real-time without interrupting control operation.

2. The engine control system of claim **1** wherein the memory comprises a non-volatile static RAM.

3. The engine control system of claim **1** wherein the set of defined relationships comprises a set of look-up tables.

4. The engine control system of claim **1** wherein the electronic control unit further comprises a microcontroller responsive to the input signal.

5. The engine control system of claim **1** wherein the electronic control unit further comprises a flash memory for storing executable code for the electronic control unit.

6. The engine control system of claim **5** wherein the flash memory comprises memory that may be rewritten to change the executable code for the electronic control unit.

7. A method of controlling an engine comprising:

providing one or more input signals in response to engine operating conditions;

producing electronic control signals in response to the input signals based on a set of defined relationships;

selectively modifying the set of defined relationships in real-time without interrupting the production of electronic control signals;

storing the set of defined relationships in a working storage area of a memory unit during operation;

storing the set of defined relationships in a second storage area of the memory unit upon power loss;

wherein the electronic control signals are used by one or more control apparatus that are operative to control engine operating conditions.

8. The engine control method of claim **7** wherein the set of defined relationships comprises a set of look-up tables.

9. The engine control method of claim **7** wherein modifying the set of defined relationships comprises modifying one or more entries in the set of look-up tables.

10. The engine control method of claim **7** further comprising storing a log of modifications that are made to the set of defined relationships.

11. The engine control system of claim **7** wherein the memory unit comprises a non-volatile static RAM.

* * * * *